FOCUS ON BIOTECHNOLOGY

Biotechnology for the Environment: Strategy and Fundamentals

Edited by

Spiros N. Agathos and Walter Reineke

Series Editors: Marcel Hofman and Jozef Anné

Kluwer Academic Publishers

Biotechnology for the Environment: Strategy and Fundamentals
Volume 3A

Edited by

SPIROS N. AGATHOS
Université Catholique de Louvain,
Louvain-la-Neuve, Belgium

and

WALTER REINEKE
Bergische Universität,
Wuppertal, Germany

KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 1-4020-0529-6

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Sold and distributed in North, Central and South America
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Printed on acid-free paper

Printed in the Netherlands.

BIOTECHNOLOGY FOR THE ENVIRONMENT:
STRATEGY AND FUNDAMENTALS
VOLUME 3A

FOCUS ON BIOTECHNOLOGY

Volume 3A

Series Editors

MARCEL HOFMAN

Centre for Veterinary and Agrochemical Research, Tervuren, Belgium

JOZEF ANNÉ

Rega Institute, University of Leuven, Belgium

Volume Editors

SPIROS N. AGATHOS

Université Catholique de Louvain,
Louvain-la-Neuve, Belgium

WALTER REINEKE

Bergische Universität,
Wuppertal, Germany

COLOPHON

Focus on Biotechnology is an open-ended series of reference volumes produced by Kluwer Academic Publishers BV in co-operation with the Branche Belge de la Société de Chimie Industrielle a.s.b.l.

The initiative has been taken in conjunction with the Ninth European Congress on Biotechnology. ECB9 has been supported by the Commission of the European Communities, the General Directorate for Technology, Research and Energy of the Wallonia Region, Belgium and J. Chabert, Minister for Economy of the Brussels Capital Region.

EDITORS PREFACE

At the dawn of the 21st century we are witnessing an expanding human population in quest of survival and continued well-being in harmony with the environment. Many segments of society are increasingly preoccupied with the battle against both diffuse and concentrated pollution, the remediation of contaminated sites, the restoration of damaged areas due to anthropogenic activities and the re-establishment of functioning biogeochemical cycles in vulnerable ecosystems. There is an enhanced awareness of the value of pollution prevention and waste minimization in industrial, urban and agricultural activities, as well as an increased emphasis on recycling. Faced with these major contemporary challenges, biotechnology is emerging as a key enabling technology, and, frequently, as the best available technology for sustainable environmental protection and stewardship.

Although the activities of microorganisms and their subcellular agents have been recognized, studied and harnessed already for many years in the environmental arena, there is a new dynamism in the in-depth understanding of the molecular mechanisms underlying the functioning of microorganisms and their communal interactions in natural and polluted ecosystems, as well as an undeniable expansion of practical applications in the form of the new industry of bioremediation. A number of distinct but increasingly overlapping disciplines, including molecular genetics, microbial physiology, microbial ecology, biochemistry, enzymology, physical and analytical chemistry, toxicology, civil, chemical and bioprocess engineering, are contributing to major insights into fundamental problems and are being translated into practical environmental solutions and novel economic opportunities.

The book set «Biotechnology for the Environment», based on a compilation of some of the outstanding presentations made at the 9th European Congress on Biotechnology (Brussels, Belgium, July 11-15, 1999), captures the vitality and promise of current advances in the field of environmental biotechnology and is charting emerging developments in the beginning of the new millennium. This first volume, subtitled 'Strategy and Fundamentals' offers an exciting bird's-eye view on carefully selected topics of basic science and methodology in the area of pollutant biodegradation and bioremediation, illustrating both the richness of the mechanistic insights and the importance of the multidisciplinary approaches for years to come. After an opening account on the robustness of several biotechnological solutions for waste minimization and pollution control in the chemical industry, a number of contributions offer state-of-the-art descriptions of the genetics and biochemistry of degradation of important recalcitrant molecules, such as halogenated aliphatic and aromatic compounds, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, detergents and chelating agents. Pesticides and chlorinated or polycyclic hydrocarbons are well-known priority pollutants and continue to be fertile areas of study given the hazards resulting from their abundance and ubiquitous presence due to historical pollution from past industrial and agricultural practices. On the other hand, detergents, chelating agents and other organic molecules at low concentrations (micropollutants, endocrine disruptors) are emerging as equally if not more insidious for the health of humans and other organisms and, thus, studies on their biodegradation are starting to gather momentum. Molecular approaches to track microbial diversity with impact on global change, novel vector-based bioaugmentation strategies for complex environmental matrices (soils, sludges, etc.) and, last but not least, transgenes as new-generation sensors for ecotoxicological monitoring, complete the picture.

The Editors hope that the integration of the depth of scientific fundamentals with the breadth of current and future environmental applications of biotechnology so evident in these selected contributions will be of value to microbiologists, chemists, toxicologists, environmental scientists and engineers who are involved in the development, evaluation or implementation of biological treatment systems. Ultimately, a new generation of environmental scientists should take these lessons to heart so that new catalysts inspired from the biosphere can be designed for safe, eco- and energy-efficient manufacturing and environmental protection.

Spiros N. Agathos   Walter Reineke

TABLE OF CONTENTS

PART 1
STRATEGIC VIEWS

APPLICATION OF THE BIOTECHNOLOGICAL POTENTIAL FOR ENVIRONMENTAL CHALLENGES IN THE CHEMICAL INDUSTRY

The biotechnological potential is ecoefficient and thus will become increasingly applied in future

GERHARD STUCKI AND PATRICK STEINLE
Ciba Specialty Chemicals Inc., WS-2090, CH-4133 Pratteln, Switzerland
Present address for Gerhard Stucki, BMG Engineering AG,
Grammetstrasse 14 CH-4410 Liestal Switzerland.
Email:gerhard.stucki@bmgeng.ch Fax:+41-619232580

Abstract

Nature has an enormous potential to cycle materials and energy. This potential, and specifically that of biological processes can be applied in the chemical industry to recycle or treat waste, wastewater, and off-gas, and thus reintegrate the man-made, synthetic chemicals into the natural cycles.

This contribution describes some powerful and innovative biotechnical processes investigated in and partly applied at Ciba Specialty Chemicals Inc., Switzerland for the breakdown of C-, Cl-, N-, S-, and P-containing molecules for water, air and soil treatment. Among these are laboratory investigations on the degradation of atrazine or chlorophenols in soils, the large-scale application of microorganisms capable of mineralising aromatic or chlorinated aliphatic compounds in fixed-film bioreactors for groundwater treatment, the anaerobic treatment of chemical effluents, or the removal of solvents from off-gas using biological trickling filters.

Although the biotechnological potential available is vast, its applicability in the environmental field is slow. Possible reasons and potential barriers to overcome are discussed from a perspective of the chemical industry. Chances for optimal solutions including biological processes increase if the approach to solve environmental challenges is holistic, if the wastewater or off-gas is well characterised, if cheap and reliable biodegradation tests are used coupled with professional interpretation of the test results, and if interdisciplinary know-how transfer occurs.

1. Introduction

Excellent solutions in the environmental field are those which avoid problems from the start. Therefore, if the principle to avoid, reduce and dispose of the wastes end of the

S.N. Agathos and W. Reineke (eds.),
Biotechnology for the Environment: Strategy and Fundamentals, 9–20.

process is strictly followed, very few environmental problems would occur, and thus not many environmental engineers and biotechnologists would be required. In reality, we are far from such an ideal situation. In fact, applying too strict a principle would make neither economical nor ecological sense in many situations. Example: it will mostly be better to collect small effluents and treat them together in a cheap and environmentally friendly way than to treat them individually, or to incinerate the wastewater with the result of a "zero-discharge facility", which is "zero discharge" in relation to wastewater but not to energy or air. Therefore, in practice, rather the optimal than the maximal solutions are looked for. Biotechnological solutions are especially advantageous in the long run, they generally require more volume (higher investment cost) than chemical and physical options, but they are often far more advantageous regarding resources including energy requirements and operation costs.

In the following chapter, case studies are presented of biological processes investigated and implemented in the chemical industry to solve environmental challenges. Some of them have been transferred to full scale, while others still wait to be applied some day. Very often, the biological process used was just one of a chain of process steps to reach required goals.

2. Biotechnological processes to remove/degrade chemicals

During the last 12 years, many biological processes were studied and partially applied at Ciba Specialty Chemicals, Switzerland, to eliminate waste chemicals (Table 1).

2.1. REMOVAL OF ORGANIC CARBON

In contrast to the food industry, where high loads and concentrations of a more or less constant composition of organic materials are converted by applying anaerobic processes, larger quantities of carbonaceous compounds are most often distilled, recycled or used as fuel replacement in the chemical industry. Cases with high volumes and loads of organic materials to be degraded are rare, and are restricted to wastewaters containing waste carbohydrates or organic acids. Such type of wastewater was generated in a dyestuff factory. The large amounts of dilute aqueous acetic acid and ethylene glycol among trace amounts of aromatic chemicals could neither be avoided nor replaced nor recovered economically and thus was pre-treated anaerobically in a 170 m^3 reactor. For the successful application, it was important to identify toxic substances inhibiting the anaerobic microorganisms. The major "toxic chemical" was sulphuric acid which was replaced by an alternative inorganic acid to avoid inhibition due to H_2S formation.